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OPTIMIZATION AND ANALYSIS OF PROCESS PARAMETERS IN MICRO-DRILLING USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

High precision and high spindle speed applications is one of the most significant factors in fundamental technologies in machining processes, which is of good productivity and quality. When the basic machining process, 'drilling' is performed below 1mm hole diameter, it is called, "Micro-Drilling", which is the precision hole drilling process. This study deals with Response Surface Methodology approach in Micro-drilling machine for optimizing the material removal rate. Drilling is performed on Brass material with machining parameters as Feed, Speed, Machining time and Depth of hole. The experiments were conducted with Box-Behken Design method based on response surface design. Analysis of variance (ANOVA) was used to determine the effect of the parameters after getting the values of MRR. The interaction of their parameters was also considered to be important. Regression analysis was performed and for MRR, a Linear model was fitted. This was done considering the significant interactions and the parameters. Finally, optimization was performed using desirability approach and experiments for confirmation were conducted.

***KEYWORDS:** Micro-drilling, Cutting tool, Material removal rate, Response Surface Methodology, Design of Experiment, Box-Behnken Design, Analysis of Variance, Regression & RSM Model*

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Original Article

I. INTRODUCTION

One of the most fundamental machine technologies is Micro drilling. It is moving high spindle speed and high precision application in manufacturing field and increasing the quality and productivity. In recent days, micro drillings are found to have great use in manufacturing to apply special items and parts. To increase the productivity of a cutting process, micro drill tools are used. The cost of a cutting tool is relatively low, but the cost incurred by tool failures is higher than the price of a cutting tool. Therefore, modeling and optimization of drilling processes are extremely significant from the cost and productivity viewpoint, for the manufacturing industry. The reason behind the cause of tool breakage and poor quality surface is the poor removal of chips in deep drilling of small diameter. High speed machining technology, the smaller the tools; the higher the spindle speed you will need to efficiently machine quality parts and avoid tool breakage [3]. It is very important to have attractive application in machining process like Fuel injection nozzles, Printed circuit boards, Camera parts, Watch parts, Mobile phones, Medical needles, Aeronautics, Computers etc. [11]

In the recent days, in many researches, a major goal in machining operations is the Material Removal Rate. In many industries, Response Surface method is widely used, which is used to analyze and optimize the

quality and characteristics by setting the design parameters. It is performed in MINITAB17 in DOE and detailed analysis is done, significant factors are recorded, thus optimal plot graph provides optimal parameters. [14]

II. THEOROTICAL CONCEPT

Response Surface Methods (RSM) is optimization, finding the best set of factor levels in achieving some goal, which dates from the 1950's. In the chemical industry, early applications were seen. About building and analyzing RSMs, Box and Draper had some wonderful references, which are very useful. Response Surface Methodology and its sequential nature is for optimizing a process First order and Second order response surface models. It also allows dealing with various responses, simultaneously (Multiple Response Optimization). Box-Behnken Designs and Central Composite Designs (CCD) as two of the major Response Surface Designs that produces them are using Minitab. Design and Analysis of Mixture Designs can also be made where the sum of the factor levels equals a constant, i.e., 100% or the totality of the components. [17]

Different models for Response surface methods are shown below,

Screening Response Model

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + \varepsilon \qquad (1)$$

The screening model that was used for the First order state involves single cross product factor and linear effects, which signifies the linear x linear interaction component.

Steepest Ascent Model

Just ignoring the cross products that give a suggestion of the curvature of the response surface that we are fitting and just looking at the first order model called the "steepest ascent model":

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon \qquad (2)$$

Optimization Model

Then, when we are near the 'top of the hill', a second order model will be fit. This includes the two second-order quadratic terms.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \varepsilon \qquad (3)$$

Steepest Ascent - The First Order Model

In first order situation - the method of steepest ascent, the first place we are not aware if the 'hill' even exists; hence, we can start from where the optimum exists. It is started in terms of the natural units and the coded units are used to perform the experiment. In other words, we can superimpose this experimentation region on to the plot of our unknown 'hill' for illustrating this concept. The experiments are obviously conducted in its natural units but the designs are specified in the coded units so as to apply them to any situation. We use a four corner points design here specifically, a 2^2 design and five center points. The first-order model is fitted now and investigated. We place in the actual data for A and B and the response measurements Y, we fit the surface. There are two main effects for this model, one cross product term and one additional parameter as the mean for the center point. In this case, the residuals have four *df* which come from the center points replication. There are five center points and four*df*among the five center points. This is started by testing for curvature. The query is whether the mean of the center points is different from the values at $(x_1, x_2) = (0,0)$ predicted from

the screening response model (main effects plus interaction). The testing was done to see whether the mean of the center points are on the plane fit by the four corner points. We can find whether a mean of the center points is above or below the plane showing curvature in the response surface, if the p-value is small. In this case, it is not significant indicating that there is no curvature. Infact, the center points fall precisely on the plane that fits the quarter points. The design has only one additional location in terms of the *x*'s, hence there is only one degree of freedom. We also check the significant effects of the factors. ANOVA shows that there is no interaction. Hence, this model shall be refit without the interaction term, leaving just the A and B terms. The average of the center points and our AOV now shows 5 *df* for residual errors. One of these is lack of fit of the additive model and there are 4 *df* of pure error as before. There is 1 *df* for curvature, and in this case, lack of fit is just the interactions from the model. Finally, to get optimum parameters, Response optimal can be selected.[18]

III. RESEARCH DESIGN

Material removal rate (MRR) is measuredas the main attributes in this study along with Machining time with input parameters as Feed, Speed, and depth of Hole. The following technique is being accepted.

Design of Experiment

Response Surface Design is created, considering three factors stated above and levels are selected from minimum to maximum as shown below.

Table 1

Factors	Low	High
Speed	12000	24000
Feed	0.0003	0.0004
DOH	2	3

Different Combinations of Factors and Respective Machining Time Are Generated After that. then, MRR is Calculated

Box-Behnken Design

To address the problem of where the experimental boundaries should be, these deigns are very useful. It is useful to avoid extreme treatment combinations, particularly. The Box-Behnken design avoids all the star points and the corner points. Just like the central composite design, it does not have a ball where all of the corner points lie on the surface of the ball. The ball is located inside the box in this design. This is defined by a 'wire frame' that is composed of the box edges. When a balloon is blown inside this wire frame box, it hardly extends beyond the box sides and it might look like this in three dimensions. Observe where the balloon touches the wire frame first; this is the place where the points are nominated for creating design. If the extreme points are a problem in the experiment, then there are some advantages to the Box-Behnken. A design is made for 15 runs, based on the factors Speed, Feed, and Depth of Hole Response design is made for fifteen runs i.e., 15 combinations as per given below.[14]

Factors: 3 Replicates: 1

Base runs: 15 Total runs: 15

Base blocks: 1 Total blocks: 1

Center points: 3

Table 2: Response Surface Regression: MRR Versus Speed, Feed, DOH Analysis of Variance

Std order	Run order	Pt type	Blocks	Speed	Feed	DOH	MT	MRR
3	1	2	1	12000	0.0005	2.5	0.416667	1.1775
7	2	2	1	12000	0.0004	3	0.625	0.942
15	3	0	1	18000	0.0004	2.5	0.347222	1.413
14	4	0	1	18000	0.0004	2.5	0.347222	1.413
2	5	2	1	24000	0.0003	2.5	0.347222	1.413
10	6	2	1	18000	0.0005	2	0.222222	1.76625
12	7	2	1	18000	0.0005	3	0.333333	1.76625
4	8	2	1	24000	0.0005	2.5	0.208333	2.355
8	9	2	1	24000	0.0004	3	0.3125	1.884
5	10	2	1	12000	0.0004	2	0.416667	0.942
6	11	2	1	24000	0.0004	2	0.208333	1.884
9	12	2	1	18000	0.0003	2	0.37037	1.05975
11	13	2	1	18000	0.0003	3	0.555556	1.05975
1	14	2	1	12000	0.0003	2.5	0.694444	0.7065
13	15	0	1	18000	0.0004	2.5	0.347222	1.413

Table 3

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	3	2.77301	0.92434	183.33	0.000
Linear	3	2.77301	0.92434	183.33	0.000
Speed	1	1.77473	1.77473	352.00	0.000
Feed	1	0.99828	0.99828	198.00	0.000
DOH	1	0.00000	0.00000	0.00	1.000
Error	11	0.05546	0.00504		
Lack-of-Fit	9	0.05546	0.00616		
Pure Error	2	0.00000	0.00000		
Total	14	2.82847			

The above table 3 shows that the more influencing factor on MRR is Speed, which is also important as P-value is 0.000, which is less than 0.5.

Regression Analysis

This study results were used to develop a mathematical model for expressing the relation between MRR and process parameters.

Regression Equation in Uncoded Units

MRR = -1.413 + 0.000078 Speed + 3533 Feed - 0.0000 DOH

Response Optimization: MRR

Parameters

Table 4

Response	Goal	Lower	Target	Upper	Weight	Importance
MRR	Target	0.7065	1.80000	2.35500	1	1

Variable Ranges

Variable Values

Speed (18000, 24000)

Feed (0.0003, 0.0004)

DOH (2, 3)

Solution

Table 5

Speed	Feed	DOH	MRR
23315	0.0004	2	1.8

MRR Response Prediction

Variable Setting

Speed 23315.2

Feed 0.0004

DOH 2

Response Fit SE Fit 95% CI 95% PI

MRR1 1.8000 0.0383 (1.7157, 1.8843) (1.6225, 1.9775)

OPTIMIZATION PLOT

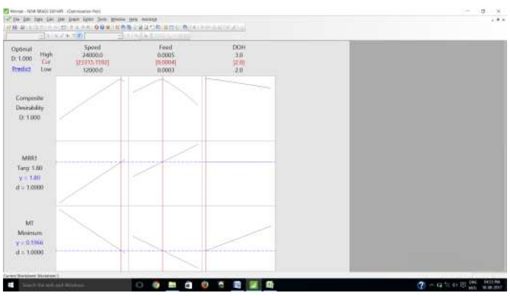

Figure.1: Optimization Plot for MRR

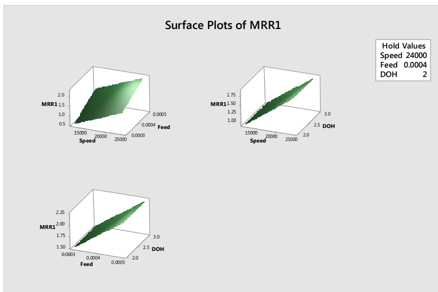

Figure 2: Optimization Plot for MRR

Optimization plot for MRR is shown in the above graph. Targeting MRR is the objective of the work. To find out the optimum values of the variables, desirability approach has been used in order to get the maximum value of MRR. It is clear from the graph that the highest value is 1.8 mm^3/min. It is obtained for the following combination of the variables 0.0004 as Feed, 24000 as Speed and 2 as DOH.

IV. CONFIRMATION TEST

Considering the Feed as 0.0004mm/rev, Speed as 24000 RPM, and DOH as 2mm, the confirmation test is carried out on a CNC Micro-drilling machine. For this, CNC program is run and after the operation is performed, MRR is calculated by using the following formula,

MRR= Initial weight- Final weight

Density x Machining time

So MRR comes out to be 1.88mm^3/min.

V. RESULTS AND DISCUSSSIONS

MRR is calculated as from Regression after the experiment as follows,

MRR = -1.413 + 0.000078 Speed + 3533 Feed - 0.0000 DOH= -1.413+0.000078x24000+3533x0.0004-0.000x2 = 1.87 mm^3/min.

MRR comes out to be 1.87 mm^3/min, as per regression equation.

Percentage difference between experimental value and predicted values is calculated as

% diff= Experimental value- Predicted value x 100

Experimental value

= 1.88-187/1.88 x 100 = 0.53 %

From above it is observed that the optimized value is worth, verification of the optimum result achieved is compared by assuming the Benchmark parameters as in between high and low i.e medium which will be 0.0004 mm/rev for Feed, 18000 RPM for Speed and 2.5 for DOH. From this MRR achieved will be 1.4187 mm^3/min which is less than optimum result obtained.[23]

VI. CONCLUSIONS

From the conventional tool, achieving micro-drilling is a very difficult, which is the hard solving problem for optimization. Hence, 0.70 mm^3/min and maximum MRR achieved from highest factors of each parameters will be 2.36 mm^3/min while MRR which is set as a Benchmark is 1.4187 mm^3/min. Taking this into consideration, it was decided to attain the mark value for Response optimization, which is above medium value and highest value and also justified through confirmation test, where Feed is medium with less Depth of hole and Speed is high, will get optimized Material Removal Rate has been workout without tool failure.

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